THE MAIN BELT AND NEA SIZE DISTRIBUTIONS: LINKED COLLISIONAL AND DYNAMICAL EVOLUTION.
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Overview: The size distribution of the main belt is governed by collisional evolution as well as by the non-collisional removal of bodies due to the combination of radiation forces and resonances. The NEA size distribution is governed in part by the size distribution of the main belt, it's primary source, but differs somewhat from the main belt due to the size dependent processes which deliver asteroids from the main belt to near-Earth space. These two size distributions provide a powerful constraint on any model of asteroid collisional evolution and NEA delivery. Additional constraints are provided by the cratering records on observed asteroids, such as Gaspra, Ida, Mathilde, and Eros, and by the cosmic ray exposure (CRE) ages of meteorites, which indicate that meter-sized bodies have collisional lifetimes on the order of 10 Myr or more in the main belt. A collisional evolution model for the main belt can fit most of these constraints with reasonable parameter choices. In addition, our results show that non-collisional removal processes, such as the Yarkovsky effect, are not strong enough to significantly alter the cratering records on asteroids (i. e. incapable of causing a significant depletion in small craters, as seen on Eros).

The Model: We use a numerical collisional evolution code based on the collisional algorithm of Petit and Farinella [1]. Our code starts with an initial binned main belt population and evolves this population through time. Collision frequencies are calculated using estimates of the intrinsic collision probability [2], and the Petit and Farinella algorithm is used to predict the outcomes of collisions between bodies in any two size bins. Both cratering and catastrophic collisions are treated. The main parameter we use that governs the collisional outcome is the critical specific energy Q^*_D, which is the energy per unit mass necessary to fragment a target and disperse half of the mass of the fragments to infinity.

In addition to collisional effects, our code also treats the size-dependent removal of bodies from the main belt by non-collisional effects, such as the Yarkovsky effect, which sweeps main belt bodies into resonances that deliver them to near-Earth space. The bodies removed from the main belt population in our model become NEAs with a dynamical lifetime on the order of a few Myr.

Varying Q^*_D as well as the size-dependent non-collisional removal rates from the main belt, within reasonable ranges, we are able to obtain main belt and NEA populations in our model, which we can compare with the observed main belt and NEA size distributions. In addition, we can compare the collisional lifetimes of meter-sized bodies in our model with the CRE ages of meteorites, and we can see if the main belt population we obtain is consistent with the cratering records on observed asteroids.

Results: Figure 1 shows the main belt population obtained from our collisional model, compared with the observed main belt population determined from direct observation and debiased Spacewatch [3] and Sloan Digital Sky Survey data [4].

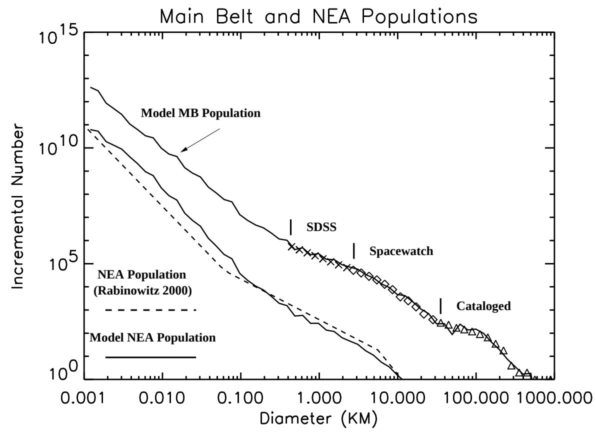

Figure 1: Main belt and NEA populations resulting from a 4,500 Myr simulation combining collisional evolution and non-collisional removal processes. The actual main belt population is given by cataloged asteroids (triangles), Spacewatch data (diamonds), and Sloan Digital Sky Survey data (X-marks). The actual NEA population (dashed line) is from the Rabinowitz 2000 estimate.

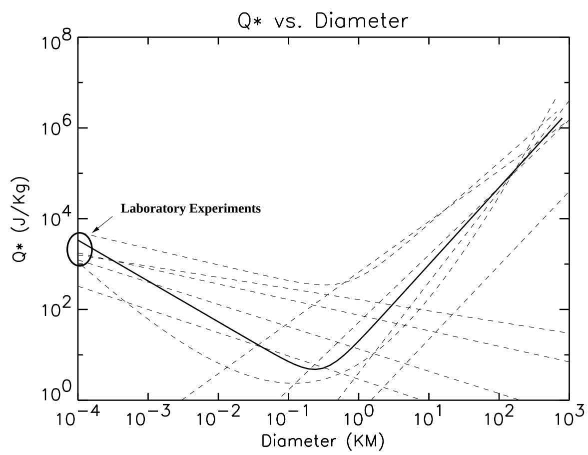

Figure 2: Solid line shows the Q^*_D law used in the simulation shown in Figure 1. The dashed lines show estimates of Q^*_D by other authors. Our Q^*_D is consistent with the estimates of other authors, and agrees with laboratory collisional experiments for targets around 10 cm.

Also shown is the NEA population obtained in our model, compared to recent estimates of the NEA population by Rabinowitz [5].

The Q^*_D vs. diameter relation that yields the population in Figure 1 is shown in Figure 2, compared with other estimates of Q^*_D for asteroids from the literature. Our estimate is well within the range of predicted values, and agrees well with

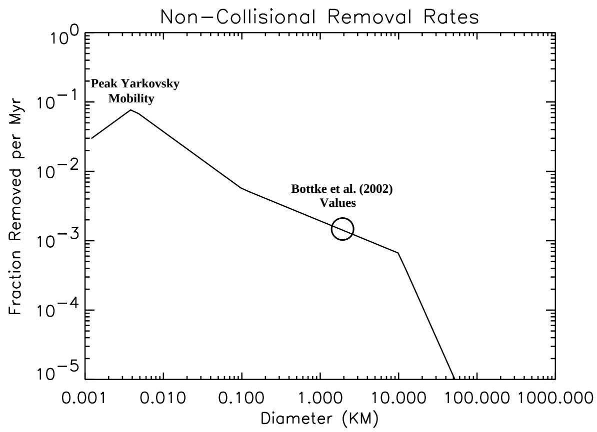

Figure 3: Non-collisional removal rates used in the the simulation shown in Figure 1. Our results are consistent with the removal rates predicted by Bottke et al. (2002) for km-scale bodies, and consistent with predictions that the Yarkovsky effect is strongest for bodies around 1-10 m in diameter.

values from laboratory studies of targets around 10 cm in diameter.

The dynamical (i. e. orbital variation) removal rates used in our model are shown in Figure 3. Our results agree with the estimate by Bottke et al. (2002) for the removal rate of km-scale bodies from the main belt [6]. In addition, our results are consistent with estimates that the Yarkovsky effect should be strongest, and hence removal should be most efficient, for bodies between 1 and 10 m in diameter.

The mean collisional lifetimes of main belt bodies in our model are shown in Figure 4. The collisional lifetime of meter-scale bodies in our model is around 7 Myr, reasonably consistent with the CRE ages of stony meteorites which indicate a mean collisional lifetime on the order of 10-20 Myr.

Discussion and Conclusions: A numerical model, which combines collisional evolution with non-collisional removal effects (i. e. resonances and the Yarkovsky effect), yields main belt and NEA populations consistent with observed size distributions, as well as with CRE ages of meteorites. These results are obtained using values for Q_D^* and non-collisional removal rates from the main belt which are consistent with estimates by other authors.

The cratering records on observed asteroids (Ida, Gaspra, Eros and Mathilde) should be consistent mutually and with the population of impactors. Thus, these cratering records serve as additional constraints. We are investigating the surface processes that will allow us to reconcile these diverse records with the evolving main belt and NEA populations.

The non-collisional removal rates we find are strong enough to have an effect on the evolution of the main belt size distribution, but the effect is relatively subtle, since the ongoing collisional cascade is very efficient at replenishing bodies lost by non-collisional effects. Several authors have suggested that the lack of small craters on Eros may be due to Yarkovsky removal of meter-scale bodies [7,8]. We find that their model would require a depletion of meter-scale bodies by several orders of magnitude in number. Such removal would require non-collisional removal rates hundreds or thousands of times larger than what we (and other authors) have found, which is unlikely. Thus, the Yarkovsky effect cannot explain the paucity of small craters on Eros.

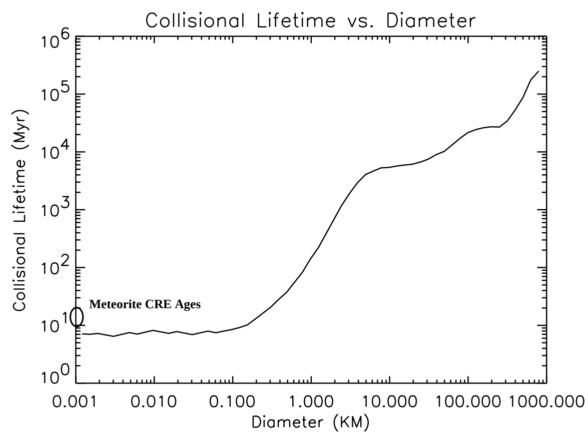

Figure 4: Mean collisional lifetimes obtained for the main belt bodies shown in Figure 1. Note that lifetimes for meter-scale bodies are close to CRE ages for stony meteorites.

References: [1] Petit, J. and Farinella, P. 1993, Celest. Mech. and Dyn. Astro. 57, pp. 1-28. [2] Bottke, W. F. and Greenberg, R. 1993, GRL 20, pp. 879-881. [3] Jedicke, R. and Metcalfe, T. S. 1998, Icarus 131, pp. 245-260. [4] Ivezic, Z. et al. 2001, AJ 122, pp. 2749-2784. [5] Rabinowitz, D. et al. 2000, Nature 403 pp. 165-166. [6] Bottke, W. F. et al. 2002, Icarus 156, pp. 399-433. [7] Bell, J. F. 2001, 32nd LPSC, abstract no. 1964. [8] Chapman, C. 2002, Icarus 155, pp. 104-118.